International Journal of Obesity (1998) 22, 440–447

http://www.stockton-press.co.uk/ijo

Energy expenditure and physical fitness in overweight *vs* non-overweight prepubertal girls

MS Treuth[1], R Figueroa-Colon[2], GR Hunter[3], RL Weinsier[3], NF Butte[1] and MI Goran[3]

[1]*USDA/ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, Houston and Department of [2]Pediatrics and [3]Nutrition Science, Energy Metabolism Research Unit, University of Alabama at Birmingham, Birmingham, USA*

OBJECTIVE: To determine whether overweight children have lower physical activity energy expenditure (EE) and fitness levels than non-overweight children.
STUDY DESIGN: Twenty-four healthy girls aged 7–10 y were divided into overweight ($>$95th percentile weight-for-height) and non-overweight (10–90th percentile) groups. Basal metabolic rate (BMR), sleeping metabolic rate (SMR), 24 h sedentary EE (SEE) and total EE (TEE) were measured by room respiration calorimetry and doubly labelled water. Physical activity EE and physical activity level (PAL) were calculated. Fitness (VO_2peak) was measured by a treadmill exercise test.
RESULTS: The overweight group had significantly higher body weight, percent fat, fat mass and fat-free mass (FFM) ($P<0.001$). The overweight girls had higher BMR, SMR, SEE and TEE ($P<0.001$), but not after adjustment for FFM. Physical activity EE and PAL were not significantly different between groups. After adjusting for FFM or weight, submaximal and peak VO_2 were not significantly different between groups.
CONCLUSIONS: We conclude that these overweight girls do not have lower physical activity EE or fitness levels than the non-overweight prepubertal girls, however, the rather high body fat of the non-overweight group may have precluded us from finding any differences between groups.

Keywords: obesity; physical activity; free-living energy expenditure; calorimetry; doubly labelled water

Introduction

Obesity is an increasingly prevalent health problem in children, affecting 22–27% of US children and adolescents.[1–3] The increasing adiposity has been partly attributed to television viewing[4] and a sedentary lifestyle.[5] Some cross-sectional studies have reported that obese children are less active than normal-weight children,[4–7] whereas others have found no differences.[8,9]

Several methods exist to assess energy expenditure (EE) and fitness. Indirect calorimetry can be used to assess basal metabolic rate (BMR) during a 30 min test or sedentary EE (SEE) during a 24 h test in a whole-room respiration calorimeter, whereas doubly labeled water (DLW) can measure free-living or total energy expenditure (TEE). Physical activity EE can be calculated as TEE $-$ (BMR $+$ thermic effect of food), with physical activity level (PAL) as TEE/BMR. Aerobic capacity or physical fitness is typically determined by measurement of maximal or peak oxygen consumption (VO_2peak).

Utilizing some of these techniques, studies have evaluated EE and fitness in children of varying levels of body fat. PAL has been found to be vary widely, ranging from 1.15–2.01, in children.[10–13] A low physical activity EE, only 16.7% of TEE, was reported in children aged 5 y.[10] Two studies comparing obese and nonobese children have reported no significant differences in TEE (measured by DLW), physical activity EE or PAL in either prepubertal children[14] or adolescents.[15] However, both studies suggested that the obese children had a reduced activity level. It is therefore of interest to combine two state-of-the-art techniques, 24 h indirect calorimetry and DLW, to compare the levels of SEE, TEE and physical activity EE in overweight *vs* non-overweight prepubertal children.

In studies comparing fitness levels of overweight and non-overweight children, conflicting results have been reported. Some studies have found decreased physical fitness in overweight children,[16,17] while others found no limitations in aerobic capacity during running and cycling.[18] Little is known about exercise economy (submaximal steady-state VO_2, VO_2/VO_2peak, heart rate and ventilation) in overweight or non-overweight children. One study of obese adolescents reported a decreased efficiency with increasing workload, since the increase in calorie output with increased walking speed was nonlinear.[19]

There is limited research available comparing overweight and non-overweight prepubertal girls for

Correspondence: Margarita S. Treuth, Ph D, USDA/ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, 1100 Bates Street, Houston, TX 77030, USA.
Received 3 February 1997; revised 2 July and 4 December 1997; accepted 16 December 1997

fitness levels and physical activity EE. In addition, no studies of which we are aware have compared overweight *vs* non-overweight prepubertal children for SEE, TEE and physical activity EE utilizing DLW and 24 h respiration calorimetry. Therefore, the purpose of this study was to utilize state-of-the-art techniques to determine whether overweight children have lower physical activity EE and fitness levels than non-overweight children.

Methods

Subjects

Twenty-four healthy girls (age range 7–10 y, Tanner stage I) were recruited through the media and schools in the Birmingham, Alabama area. Subjects were unrestricted as to racial/ethnic background. Girls were divided, based on weight-for-height, into two groups. Girls in the overweight group ($n=12$) were >95th percentile weight-for-height, while girls in the non-overweight group ($n=12$) were in the 10–90th percentile weight-for-height, according to the National Center for Health Statistics.[20] Individuals with cardiovascular disease, anaemia, diabetes, significant renal or hepatic disease, hypothyroidism, musculoskeletal problems, those who took medications on a regular basis or those on special diets, were excluded from the study. All participants and their parents provided written informed consent to participate in this study, which was approved by the Institutional Review Board of the University of Alabama at Birmingham (UAB).

Testing sequence

Children were admitted to the General Clinical Research Center (GCRC) at the UAB Hospital at 07.00 h, after a 12 h overnight fast. After resting quietly, BMR was measured. Body composition was measured by dual-energy X-ray absorptiometry (DXA) later that day. Children in the overweight group spent one day in the GCRC, whereas the non-overweight group spent three days in the GCRC. Meals were prepared and consumed in the GCRC while admitted to the GCRC. The evening prior to the calorimeter test at approx. 18.00 h, a baseline urine was collected and the DLW dose given. On day 2 for the overweight group and day 4 for the non-overweight group, subjects underwent the 24 h calorimeter test. The urine collected in the calorimeter for the TEE determinations were the second and third voids of the morning following dosing, with the first void of the day discarded. Subjects were fed meals prepared by the GCRC at around 08.00, 12.00 and 17.00 h with snacks at 10.00 and 14.00 h. The children exited the calorimeter the following morning. Approximately 14 d later, the children returned under fasted conditions in the morning for the treadmill test and for collection of the final urines for the DLW measurements.

Dietary analysis

Subjects were fed a balanced diet while in the GCRC and the calorimeter. This diet was derived from the American Diabetes Association exchange lists for meal planning, designed to approximate 50% carbohydrate, 30% fat and 20% protein. The energy intake in the groups differed because the children were involved in different protocols; that is, data were pooled from two protocols made in the same laboratory. Children in the non-overweight group were fed *ad libitum* (350 kJ/kg of body weight), whereas intake in the overweight group was based on the child's weight (188 kJ/kg of body weight). These children were not on an energy restricted diet. The main variables of interest were total energy intake and percent of energy from carbohydrate, protein and fat. Food records were analyzed using the Minnesota Database System (Minneapolis, MN).

Body composition

Body composition was assessed by DXA (DPX-L, Lunar Radiation Corp., Madison, WI). For those children weighing <30 kg (non-overweight group), the scan was analyzed using the Pediatric Software (Version 1.5e) which uses a higher tube current and smaller collimation for greater contrast. For those subjects weighing >30 kg (overweight group), the scan was analyzed using the Adult Software (Version 3.6z). The DXA allows for determination of total and regional lean tissue mass, fat tissue mass (FM), and bone mineral content. Fat-free mass (FFM) is defined here as the sum of lean tissue mass and bone mineral content. The subject was asked to lie motionless on a table for approx. 20 min.

VO_2peak and exercise economy

Fitness capacity was measured by a VO_2peak test. The treadmill protocol involved a constant speed of 2.5 mph at an initial 0% grade for the first 4 min. The average of min 3 and 4 constituted the steady-state. The grade was then increased to 10%. Every 2 min thereafter, the grade was increased by 2.5% to a maximum of 22.5%, when speed was increased by 0.6 mph. Exercise measures (VO_2, VO_2/VO_2peak, ventilation and heart rate) and respiratory quotient (RQ) were examined during the steady-state period. VO_2peak was determined by an RQ >1.0, heart rate >195 bpm and volitional fatigue. A Sensormedics 2900 metabolic cart (Sensormedics, Yorba Linda, CA) was used to analyse respiratory gases. The coefficient of variation (CV) for VO_2peak is 5–7%.

Energy expenditure (EE)

1. Basal metabolic rate (BMR). BMR was determined in the morning after a 12 h overnight fast. The subjects reported to the GCRC at 07.00 h. After resting quietly for 30 min, BMR was determined using a Deltatrac system (Sensormedics) for 30 min. BMR was calculated using the equation of de Weir.[21] The CV for BMR is 5.8%.

2. Calorimeter measurements of EE and substrate oxidation. The subjects spent either 1 d (overweight group) or 3 d (non-overweight group) in the GCRC prior to the 24 h calorimetry measurements, depending on which protocol the children were involved in. Measurements of 24 h EE and substrate oxidation were taken in a whole-room respiration calorimeter (3.38 m long, 2.11 m wide and 2.58 m high). The calorimeter design characteristics and calibration have been previously described in detail.[22] Briefly, the room was equipped with a fold-out bed, desk, chair, lamp, refrigerator, toilet, sink, TV/VCR and telephone. Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were continuously measured by the magnetopneumatic differential O_2 analyser (Magnos 4G, Hartmann & Braun, Frankfurt Germany) and the NDIR industrial photometer differential CO_2 analyser (Uras 3G, Hartmann & Braun). The calorimeter was calibrated before each subject entered the chamber. The zero calibration was set simultaneously for both analyzers. The full scale was set at 0–1% and 0–2% for the CO_2 and O_2 analyzers, respectively. Based on duplicate studies in 19 children, the average CV for 24 h EE was 5.6% and for 24 h RQ was 2.0% (R. Figueroa-Colon, unpublished observations).

The subjects entered the calorimeter at 08.00 h. During the stay in the calorimeter, the subject was not allowed to exercise, although freedom of movement was permitted at all times during the day. The subject was awakened the following morning (06.30 h). The subject exited the room after 23 h in the chamber, allowing time for calibration before the next subject entered. Sleeping metabolic rate (SMR) and 24 h SEE were calculated by the de Weir equation.[21] All measures of EE were extrapolated over 24 h and expressed as kJ/d. For the purposes of this study, SMR was determined by averaging EE from the time when the child went to sleep until she was awakened. Protein oxidation was determined from 24 h urinary urea nitrogen excretion. Carbohydrate and fat oxidations were calculated from the 24 h nonprotein respiratory quotient (npRQ) and expressed as percentages of nonprotein EE or NPEE.[23]

3. Free-living energy expenditure. DLW was used to measure TEE over a 14-day free-living period. A baseline urine sample was collected in the evening at the GCRC prior to the 24 h calorimetry, and was followed by oral administration of DLW at approximate doses of 0.15 g of $H_2{}^{18}O$ and 0.12 g of ^2H_2O per kg body mass. A total of four timed urine samples were collected post-dose. Two were collected in the morning following dosing (in the calorimeter), with the overnight period assuring isotope equilibration. Two urine samples were collected in the morning 14 d later. This protocol minimizes error due to diurnal variation in isotope turnover,[24] while reducing the effects of analytical error. Samples were analysed in triplicate for $H_2{}^{18}O$ and ^2H_2O using a Fisons-VG Optima Isotope ratio mass spectrometer (VG Ltd, Manchester, UK). The average standard deviation (s.d.) for triplicate analysis using the sample preparation procedures was around 4 o/oo for deuterium and 0.2 o/oo for ^{18}O at the laboratory.

Turnover rates and zero-time dilution spaces of $H_2{}^{18}O$ and ^2H_2O were calculated from the slope and intercept of the regression line between the natural logarithm of isotope enrichment in urine and time after dosing, as previously described.[12] The dilution space ratios were 1.0466 ± 0.0201 and 1.0501 ± 0.0184 in the overweight and non-overweight groups, respectively. These dilution space ratios were not significantly different from each other. The mean of each group was used for all calculations. CO_2 production rate was calculated according to equation R2 of Speakman *et al*,[25] which is a modification of equation A6 of Schoeller *et al*,[26] based on *post-hoc* evaluation of the group mean deuterium : oxygen-18 dilution space ratio. CO_2 production rates were converted to EE using the de Weir equation[21] using the food quotient (FQ) of the diet based on the child's diet composition from 4 d food records (FQ = 0.88). Accurate measurement of the FQ is not critical for interpretation of DLW data, as TEE estimates will be in error by only 1% for 0.01 unit error in FQ. Total EE was calculated with the de Weir equation.[21] Assuming that 10% of TEE was due to the thermic effect of food,[27] physical activity EE was calculated as $TEE - (BMR + 0.1 \times TEE)$. PAL was calculated as TEE/BMR.

Statistical analyses

Comparisons between groups were conducted using one-way ANOVA. For those variables of interest which were significantly different between the groups, FFM and in some cases, FM or weight, were used as covariates. All data presented using the ANCOVA is expressed as the mean ± s.e.m. First for these ANCOVAs, the homogeneity of regression slopes was completed. All data were analysed by SAS for Windows (Cary, NC) with significance set at $P < 0.05$.

Results

Subject characteristics (Table 1)

There were no significant differences in age or height between the two groups. The overweight group had significantly higher body weight, percent fat, FM and FFM than the non-overweight group ($P < 0.001$).

Table 1 Characteristics of 24 prepubescent overweight and non-overweight girls aged 7–10 y

	Overweight Group ($n=12$)	*Non-overweight Group* ($n=12$)
Age (y)	8.7 ± 0.7	8.2 ± 1.0
Height (cm)	134.2 ± 9.1	129.2 ± 6.5
Weight (kg)	46.5 ± 9.0	28.5 ± 3.5*
Percent fat (%)	39.3 ± 6.4	27.6 ± 5.0*
Fat mass (kg)	18.1 ± 6.5	7.7 ± 2.0*
Fat-free mass (kg)	26.9 ± 3.2	19.9 ± 2.3*

Values are expressed as mean ± s.d.
* Significantly different from the overweight group ($P<0.001$).

Energy intake
There were no significant differences in the percent of calories from protein (12 ± 1 *vs* 14 ± 1%), carbohydrate (63 ± 1 *vs* 61 ± 1%) or fat (27 ± 1 *vs* 27 ± 1%) between the overweight and the non-overweight groups, respectively, for the day in the calorimeter. Thus, the FQs of the diets were identical (0.92 ± 0.01). No differences in energy intake between the overweight (9012 ± 2017 kJ/d) or the non-overweight (10 033 ± 2582 kJ/d) groups were evident (Table 2).

Energy intake was not significantly different from 24 h EE in the calorimeter for the overweight group. However, energy intake was significantly greater than 24 h EE ($P<0.001$), indicating a positive energy balance for the day in the calorimeter in the non-overweight group.

Energy expenditure (Table 2)

Basal metabolic rate (BMR). BMR was 929 kJ/d higher in the overweight children ($P<0.001$) and remained significantly different between the groups when adjusted for energy balance ($P<0.01$). However, after adjusting for FFM, the two groups were no longer different. There were no differences in basal npRQ and thus no differences in carbohydrate or fat oxidation at rest (data not shown).

Calorimeter measurements of EE. The overweight children had a 946 kJ/d higher absolute SMR ($P<0.001$). SMR remained significantly greater in the overweight group after the data were adjusted for energy balance ($P<0.05$), but not when adjusted for FFM. The time spent in sleep was 509 ± 33 min for the overweight and 543 ± 62 min for the non-overweight group. This corresponded to an EE during this time period of 1916 ± 326 kJ and 1703 ± 368 kJ in the overweight and non-overweight children, respectively. The overweight girls also had a 2176 kJ/d higher 24 h SEE ($P<0.001$) and was also significantly greater when adjusted for energy balance ($P<0.001$). The differences disappeared when adjusted for FFM and when adjusted for both FFM and FM (adjusted values: overweight 7510 ± 238 and non-overweight 7217 ± 222 kJ/d). The correlations between SEE and FFM were $R^2=0.50$ [SEE (kJ/d) = 234 × FFM (kg) + 2176] and $R^2=0.34$ [SEE (kJ/d) = 184 × FFM (kg) + 2665, both $P<0.05$] for the overweight and the non-overweight groups, respectively. The correlations between SEE and weight were $R^2=0.70$ [SEE (kJ/d) = 96 × Weight (kg) + 3954] and $R^2=0.65$ [SEE (kJ/d) = 163 × Weight (kg) + 1678, $P<0.01$] for the overweight and the non-overweight groups, respectively.

There was a significant difference in 24 h npRQ, with higher values in the non-overweight group ($P<0.01$). Carbohydrate utilization (%NPEE) was

Table 2 Energy expenditure and substrate oxidation in prepubescent girls.

	Overweight group ($n=12$)		*Non-overweight group* ($n=12$)	
Basal respiration calorimetry				
BMR (kJ/d)	5427 ± 557		4498 ± 481**	
BMR adj FFM (kJ/d)	4895 ± 155		4845 ± 155	
npRQ	0.86 ± 0.04		0.86 ± 0.05	
24 h respiration calorimetry				
SMR (kJ/d)	5435 ± 724		4489 ± 611**	
SMR adj FFM (kJ/d)	4946 ± 234		4937 ± 222	
SEE (kJ/d)	8494 ± 1096		6318 ± 711**	
SEE adj FFM (kJ/d)	7694 ± 293		7050 ± 272	
npRQ	0.89 ± 0.03		0.94 ± 0.03*	
Carbohydrate oxidation (%NPEE)	64.6 ± 11.6		81.3 ± 11.4*	
Fat oxidation (%NPEE)	35.4 ± 11.6		18.7 ± 11.4*	
Energy intake (kJ/d)	9012 ± 2017		10033 ± 2582	
Energy balance (kJ/d)	406 ± 1703		3720 ± 2406**	
Doubly Labelled Water	group ratio	(1.034 ratio)	group ratio	(1.034 ratio)
TEE (kJ/d)	8406 ± 1322	(8833 ± 1264)	6586 ± 912**	(7021 ± 920)
TEE adj FFM (kJ/d)	7489 ± 356	(7800 ± 362)	7502 ± 356	(7853 ± 362)
Physical Activity EE (kJ/d)	2197 ± 808	(2580 ± 767)	1556 ± 1017	(1947 ± 1011)
Activity EE adj FFM (kJ/d)	1845 ± 356	(2322 ± 355)	1908 ± 356	(2205 ± 355)
Physical Activity Level	1.6 ± 0.2		1.5 ± 0.3	

Values are expressed as mean ± s.d., except for adjusted values (mean ± s.e.m.). * Significantly different from the overweight group ($P<0.01$). ** Significantly different from the overweight group ($P<0.001$).
BMR = basal metabolic rate, FFM = fat-free mass, npRQ = nonprotein respiratory quotient, SMR = sleeping metabolic rate, SEE = sedentary 24 h energy expenditure, NPEE = nonprotein energy expenditure, TEE = total energy expenditure.

higher in the non-overweight group ($P < 0.01$); whereas fat utilization (%NPEE) was lower in the non-overweight group ($P < 0.01$) (Table 2). After adjusting either carbohydrate or fat oxidation for FFM, there was still a significant difference between the two groups ($P < 0.01$). As mentioned in the energy intake section, the non-overweight group was in a positive energy balance. The differences in energy balance explained the higher npRQ in the non-overweight group. When carbohydrate and fat oxidation were adjusted for energy balance, there was no longer a significant difference between the two groups. The adjusted values were: carbohydrate oxidation 68.1 ± 3.8 and 78.1 ± 3.6%NPEE and fat oxidation 31.9 ± 3.8 and 21.9 ± 3.6%NPEE for the overweight and non-overweight groups, respectively.

Doubly labelled water. TEE was significantly greater in the overweight group ($P < 0.001$). TEE was no longer significantly different between groups when adjusted for FFM, both FFM and FM, or weight. When adjusted for body weight, the values for the overweight and the non-overweight groups were 7544 ± 385 and 7448 ± 385 kJ/d, respectively. The turnover rates for ^{18}O for the overweight and non-overweight groups were -0.131 ± 0.014 and -0.157 ± 0.023 d^{-1}, respectively. The turnover rates for ^{2}H for the overweight and non-overweight groups were -0.0943 ± 0.0112 and -0.118 ± 0.0219 d^{-1}, respectively. No significant differences were observed between the groups for activity EE or PAL. The correlations between TEE and FFM were $R^2 = 0.61$ [TEE (kJ/d) = 331 × FFM (kg) − 427, $P < 0.01$] and $R^2 = 0.11$ ($P = 0.28$) for the overweight and the non-overweight groups, respectively. The correlations between TEE and weight were $R^2 = 0.40$ [TEE (kJ/d) = 92*Weight (kg) + 4063, $P < 0.05$] and $R^2 = 0.18$ (P = 0.17) for the overweight and the non-overweight groups, respectively.

TEE, AEE and PAL were also calculated using a dilution space ratio of 1.034 as recommended by Coward *et al*,[28] as shown in Table 2. TEE was not significantly different between the groups when adjusted for FFM, both FFM and FM, or weight. AEE and PAL were also not different between the two groups.

VO_2peak and submaximal exercise (Table 3)

There were no differences in either submaximal or peak heart rates or respiration rates between the groups. The overweight group had significantly higher peak ventilation ($P < 0.01$), with a slightly, but not significantly ($P = 0.055$) higher submaximal ventilation. Submaximal and peak VO_2 were greater in the overweight group ($P < 0.01$), with no differences in VO_2/VO_2peak ratio. Expressing these in terms of body weight, the values were 14.7 ± 2.6 and 16.6 ± 2.5 ml/kg/min for submaximal VO_2, and 32.9 ± 5.1 and 23.1 ± 5.3 ml/kg/min for VO_2peak. However, when ANCOVAs were completed using FFM as the covariate, no differences between the overweight and non-overweight groups were evident for submaximal VO_2, peak VO_2 or peak ventilation. When weight was used as a covariate, there were no significant differences between the groups for submaximal VO_2 or for VO_2peak. The steady-state RQ was significantly lower in the overweight group ($P < 0.05$), with no differences in RQ at peak exercise. Treadmill time was significantly longer in the non-overweight group by 1 min 48 sec ($P < 0.05$). Significant relationships were observed between TEE and submaximal and peak VO_2; and AEE and submaximal and peak VO_2 ($P < 0.05$). However, these were not significant when FFM was used as a partial variable.

Table 3 Exercise economy and fitness at steady-state and peak exercise in prepubescent girls

	Overweight group ($n = 12$)	Non-overweight group ($n = 12$)
Steady-State		
Heart Rate (bpm)	129 ± 11	125 ± 10
Respiration Rate	35 ± 7	35 ± 9
Ventilation (1/min)	17.7 ± 5.0	14.2 ± 3.1
VO_2 (ml/min)	682 ± 121	473 ± 70**
VO_2 adj for FFM (ml/min)	580 ± 24	575 ± 24
VO_2 adj for weight (ml/min)	570 ± 21	585 ± 21
VO_2/VO_2 peak	0.45 ± 0.07	0.44 ± 0.06
RQ	0.83 ± 0.06	0.90 ± 0.04**
Peak		
Heart Rate (bpm)	199 ± 9	195 ± 10
Respiration Rate	61 ± 7	63 ± 15
Ventilation (l/min)	50.2 ± 8.9	37.6 ± 7.7**
Ventilation adj FFM (l/min)	43 ± 2.5	45 ± 2.5
VO_2 (ml/min)	1530 ± 238	1076 ± 152**
VO_2 adj for FFM (ml/min)	1326 ± 48	1280 ± 48
VO_2 adj for weight (ml/min)	1361 ± 63	1245 ± 63
RQ	1.1 ± 0.05	1.1 ± 0.06
Treadmill time (min)	11.6 ± 1.9	13.4 ± 1.9*

Values are expressed as mean ± s.d., except for adjusted values (mean ± s.e.m.). * Significantly different from the overweight group ($P < 0.05$). ** Significantly different from the overweight group ($P < 0.01$). VO_2 = volume of oxygen consumption, FFM = fat-free mass, RQ = respiratory quotient.

Discussion

In this study, energy expenditure and substrate oxidation were adjusted for energy balance and for body composition. After adjusting for energy balance, the differences between the groups for BMR, SMR and 24 h SEE remained. Although we detected differences in substrate oxidation between the groups, with the non-overweight group having greater carbohydrate oxidation, these differences were due to the positive energy balance in the non-overweight children. (This was because the non-overweight group was fed *ad libitum* and the overweight group was fed a controlled diet.) Yet, after adjusting for body composition, the observed differences in BMR, SMR and 24 h SEE between overweight and non-overweight prepubertal girls were no longer apparent. With a sample size of 12 subjects per group, we could detect a difference of 502 kJ between each group for the BMR measurements with a power of 0.81. The TEE (unadjusted) was greater in the overweight girls, and these differences were thus explained by the higher FFM and by the higher body weight. No differences were found between the groups in physical activity EE or physical activity level. This lack of differences may be due to the rather high body fat in the non-overweight group.

In addition to the ANCOVA procedures, stepwise regression was run after combining the groups in order to examine whether there were any relationships between EE measures and body composition. The results were similar, that is, FFM entered into the regression model for those variables that were significantly different between the two groups. The entire group was heterogeneous, in that there was some overlap in FFM between groups. Positive correlations were found for the entire group between SEE and FFM ($R^2 = 0.76$, Figure 1), between TEE and FFM ($R^2 = 0.65$), and between TEE and weight ($R^2 = 0.61$, Figure 2).

Our findings of no differences between the groups after adjusting for body composition, agree with previous investigators[11,14,15,29] despite differences in study design and methodology. Two cross-sectional studies[11,29] examined the relationship between EE *vs* fatness in infants and children, and reported no relationships between TEE, BMR or activity EE and fatness in children or fatness in parents. Comparing children divided into groups based on skinfold fatness, Delany *et al*[14] reported no differences in FFM, BMR and TEE, but suggested a reduced PAL in the obese children. Their group in the highest tertile of skinfold fatness was similar to our non-overweight group, in terms of fatness measured by DXA (29% *vs* 28%); whereas our overweight subjects were fatter (39% body fat). The TEE of our overweight group was lower in comparison.[14] Our children were approx 8.5 y of age with a PAL of 1.5–1.6 ± 0.2, compared to approx 10 y with a PAL of 1.7–1.8 ± 0.1.[14] It is likely that there is too much variance to see a significant difference between the two studies. Also, because the regression of TEE *vs* BMR does not go through the origin, PAL will be lower in subjects with a lower BMR. In addition, Torun *et al*[30] reported PAL's for girls aged 5–9 y from industrialized societies to be 1.58 (data compiled from four studies, $n = 232$ child-ren). Thus, the PAL seen in our children agrees with their data.

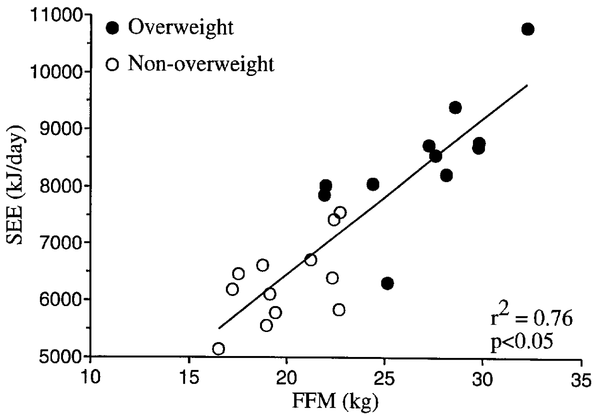

Figure 1 Relationship between sedentary energy expenditure (SEE) and fat-free mass (FFM) in overweight (closed circles) and non-overweight (open circles) prepubertal girls.

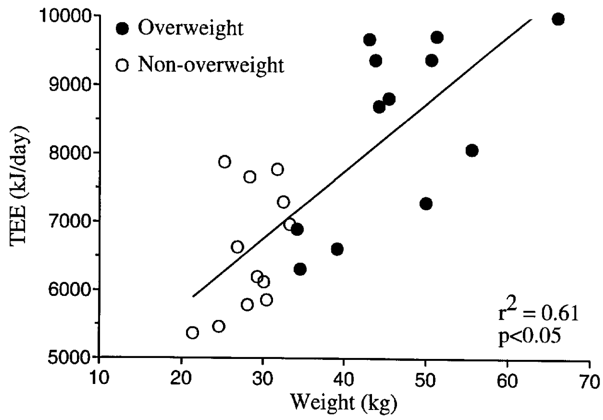

Figure 2 Relationship between total energy expenditure (TEE) and weight in overweight (closed circles) and non-overweight (open circles) prepubertal girls.

In Table 2, the TEE was reported using the group mean dilution space ratio and also using a ratio of 1.034 as recommended by Coward *et al.*[28] Using the group's mean ratio, the overweight subject's free-living energy expenditure (TEE) was 88 kJ/d lower than their energy expenditure in a confined room (SEE). For the normal-weight group, the free-living was only 268 kJ/d higher than the confined expenditure. However, if a dilution space ratio of 1.034 is used, the TEE is greater than the SEE for both groups. The difference between the TEE and SEE are 339 kJ for the overweight group and 703 kJ for the non-overweight group.

When we compare our two groups using both the TEE and BMR data, the overweight children appear as active as the non-overweight children, since the PALs (TEE/BMR) were similar. The slightly (but not significantly) higher physical activity EE could indicate that it costs the overweight children more energy to do the same amount of activity. Our treadmill data supports this. During steady-state walking at 2.5 mph, the overweight group had a significantly higher VO_2 than the non-overweight group, and consequently, expended more energy doing the same amount of activity. This is due to the higher FFM and weight of the overweight children. Gutin and Manos,[31] who prefer a movement index, (that is, activity EE/body weight), reported that obese girls were significantly less active than nonobese girls. However, when calculating this movement index, we found no significant differences between groups (48 ± 17 *vs* 55 ± 38 kJ/kg). The mean differences may indicate that there could be differences between groups, but we cannot detect any differences with our sample size and power.

To explore the possibility of more movement in the non-overweight group, we calculated the amount of time spent in activity that was of the same energy expenditure as the steady-state walking. To do these calculations, we determined (1) the submaximal treadmill exercise cost [(steady-state $VO_2 - $BMR $VO_2) \times 5$ kcal/l O_2], and (2) the amount of time spent during the free-living situation at this energy level (activity EE in kcal/the submaximal exercise cost in kcal/min). We are assuming that the daily energy cost of activity in the free-living environment is similar to the cost of walking at our steady-state level. The amount of time spent in activity similar to steady-state low intensity walking was not different ($P = 0.7$) between the overweight (215 ± 60 min) and non-overweight (257 ± 201 min) groups. Compared to the DLW data, when TEE was adjusted for body weight, there were no differences between the groups. Thus, the extra energy required to move around in the overweight children is due to the higher body mass.

One consideration is the definition of our groups. If normal-weight was defined as the 20–85th percentile, three subjects would be excluded. Statistical analysis revealed the same conclusions with these subjects removed. The lack of activity differences between groups may be related in part to the high fatness in the non-overweight group. It would be interesting to compare these girls to a group with a lower body fat to determine if activity levels differ.

VO_2peak differences between the groups were due to the higher FFM or weight in the overweight group. In contrast, several studies[16,17,32] have demonstrated that obese children are generally less fit than non-obese children. A study in girls aged 7–17 y reported strong associations at the extremes of body composition levels, that is the most obese girls had the lowest fitness levels.[32]

We also did not find any differences in submaximal VO_2 between the groups after adjusting for FFM. This is in agreement with a previous study which reported that EE of walking on a treadmill, adjusted for body weight or FFM, was not greater in obese than non-obese children.[33] It may be that at higher steady-state workloads above our intensity level, exercise economy may differ between the overweight and non-overweight child.

In conclusion, these overweight prepubertal girls were not significantly different from the non-overweight girls for BMR, SMR, SEE, TEE and VO_2peak after adjusting for differences in FFM. The higher TEE could also be explained by the higher body weight in the overweight group. Activity EE and PALs were not significantly different. Thus in this sample, using state-of-the-art techniques we have shown that our sample of overweight prepubertal girls do not have lower physical activity EE or fitness levels than non-overweight girls. However, the non-overweight girls did have a rather high body fat which may have precluded us from finding any differences between the groups. Further studies are needed to examine the possibility that reduced physical activity EE is a predisposing factor to the development of obesity in children.

Acknowledgements

We would like to thank the children for participating in this study. This study was supported by grants to M. Treuth (GCRC Grant #M01-RR00032), M. Treuth and G. Hunter (UAB School of Education Grant), R. Figueroa-Colon (NIH RR00032, DK02244) and M. Goran (USDA and R29 HD 32668).

References

1 Gortmaker SL, Dietz WH, Sobol AM, Wehler CA. Increasing pediatric obesity in the United States. *Am J Dis Children* 1987; **141**: 535–540.
2 National Health and Nutrition Examination Survey. Prevalence of overweight among adolescents – United States, 1988–91. *MMWR* 1994; **43**(44): 818–821.
3 Public Health Service. *Healthy people 2000: National health promotion and disease prevention objectives–full report, with commentary.* DHHS publication no. (PHS)91-50212.: US Department of Health and Human Services: Washington, DC, 1991.
4 Dietz WH, Gortmaker SL. Do we fatten our children at the television set? Obesity and television viewing in children and adolescents. *Pediatrics* 1985; **75**: 807–812.
5 Gortmaker SL, Dietz WH, Cheung LWY. Inactivity, diet, and the fattening of America. *J Am Diet Assoc* 1990; **90**: 1247–1252.
6 Fontvieille AM, Ravussin E. Metabolic rate and body composition of Pima Indian and Caucasian children. *Crit Rev in Food Sci and Nutr* 1993; **33**: 363–368.
7 Sunnegardh J, Bratteby LE, Hagman U, Samuelson G, Sjolin S. Physical activity in relation to energy intake and body fat in 8 and 13-year-old children in Sweden. *Acta Paediatr Scand* 1986; **75**: 955–963.
8 Maffeis C, Micciolo R, Zoccante L, Zaffanello M, Pinelli L. Energy expenditure in obese and normal weight schoolchildren. *Acta Paediatr Scand* 1991; **80**: 1145–1149.
9 Marti B, Vartianen E. Relations between leisure time exercise and cardiovascular risk factors among 15-yr-olds in eastern Finland. *J Epidemiol Commun Health* 1989; **43**: 228–233.
10 Fontvieille AM, Kriska A, Ravussin E. Decreased physical activity in Pima Indian compared with Caucasian children. *Int J Obes* 1993; **17**: 445–452.

11 Goran MI, Carpenter WH, McGloin A, Johnson R, Hardin JM, Weinsier RL. Energy expenditure in children of lean and obese parents. *Am J Physiol* 1995; **268**: E917–E924.
12 Goran MI, Carpenter WH, Poehlman ET. Total energy expenditure in 4–6 year old children. *Am J Appl Physiol* 1992; **264**: E706–E711.
13 Livingstone MBE, Coward WA, Prentice AM, Davies PSW, Strain JJ, McKenna PG, Mahoney CA, White JA, Stewart CM, Kerr MJ. Daily energy expenditure in free-living children: comparison of heart-rate monitoring with the doubly labeled water ($^2H_2\,^{18}O$) method. *Am J Clin Nutr* 1992; **56**: 343–352.
14 DeLany JP, Harsha DW, Kime J, Kumler J, Melancon L, Bray GA. Energy expenditure in lean and obese prepubertal children. *Obes Res* 1995; **3**: 67–72.
15 Bandini LG, Schoeller DA, Dietz WH. Energy expenditure in obese and nonobese adolescents. *Pediatr Res* 1990; **27**: 198–203.
16 Boileau RA, Lohman TG, Slaughter MH. Exercise and body composition of children and youth. *Scand J Sports Sci* 1985; **7**: 17–28.
17 Sasaki J, Shindo M, Tanaka H. A long-term aerobic exercise program decreases the obesity index and increases the HDL-C concentration in obese children. *Int J Obes* 1987; **11**: 339–346.
18 Maffeis C, Schena F, Zaffanello M, Zoccante L, Schutz Y, Pinelli L. Maximal aerobic power during running and cycling in obese and non-obese children. *Acta Paediatrica* 1994; **83**: 113–116.
19 Katch V, Becque D, Marks C, Moorehead C, Rocchini A. Oxygen uptake and energy output during walking of obese male and female adolescents. *Am J Clin Nutr* 1988; **47**: 26–32.
20 Hamill PVV, Drizd TA, Johnson CL, Reed RB, Roche AF, Moore WM. Physical growth: National Center for Health Statistics percentiles. *Am J Clin Nutr* 1979; **32**: 607–629.
21 de Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* 1949; **109**: 1–9.
22 Treuth MS, Hunter GR, Weinsier RL, Kell SH. Energy expenditure and substrate utilization in older women after strength training: results from a 24 h calorimeter. *J Appl Physiol* 1995; **78**: 2140–2146.
23 Elia M, Livesey G. Theory and validity of indirect calorimetry during net lipid synthesis. *Am J Clin Nutr* 1988; **47**: 591–607.
24 Speakman JR, Racey PA. Doubly labeled water: errors in the evaluation of oxygen isotope turnover due to temporal variation in CO_2 production do not always co-vary with dilution space estimate. *J Theor Biol* 1989; **141**: 547–556.
25 Speakman JR, Nair KS, Goran MI. Revised equations for calculating CO_2 production from doubly labeled water in humans. *Am J Physiol* 1993; **264**: E912–E917.
26 Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jecquier E. Energy expenditure by doubly labeled water: valid in humans and proposed calculations. *Am J Physiol* 1986; **250**: R823–R830.
27 Maffeis C, Schutz Y, Zoccante L, Micciolo R, Pinelli L. Meal-induced thermogenesis in lean and obese prepubertal children. *Am J Clin Nutr* 1993; **57**: 481–485.
28 Coward WA, Ritz P, Cole TJ. Revision of calculations in the doubly labeled water method for measurement of energy expenditure in humans. *Am J Physiol* 1994; **267**: E805–E807.
29 Davies PSW, Wells JCK, Fieldhouse CA, Lucas A. Parental body composition and infant energy expenditure. *Am J Clin Nutr* 1995; **61**: 1026–1029.
30 Torun B, Davies PSW, Livingstone MBE, Paolisso M, Sackett R, Spurr GB. Energy requirements and dietary energy recommendations for children and adolescents 1-to-18 years old. *Eur J Clin Nutr* 1996; **50** (Suppl 1): S37–S80.
31 Gutin B, Manos TM. Physical activity in the prevention of childhood obesity. *Ann NY Acad Sci* 1993; **699**: 115–126.
32 Malina RM, Beunen GP, Claessens AL, Lefevre J, Eynde BV, Renson R, Vanreusel B, Simons J. Fatness and physical fitness of girls 7 to 17 years. *Obes Res* 1995; **3**: 233–240.
33 Maffeis C, Schutz Y, Schena F, Zaffanello M, Pinelli L. Energy expenditure during walking and running in obese and nonobese prepubertal children. *J Pediatrics* 1993; **123**: 193–199.